



High Performance Two-Color One Megapixel CMOS ROIC for QWIP Detectors

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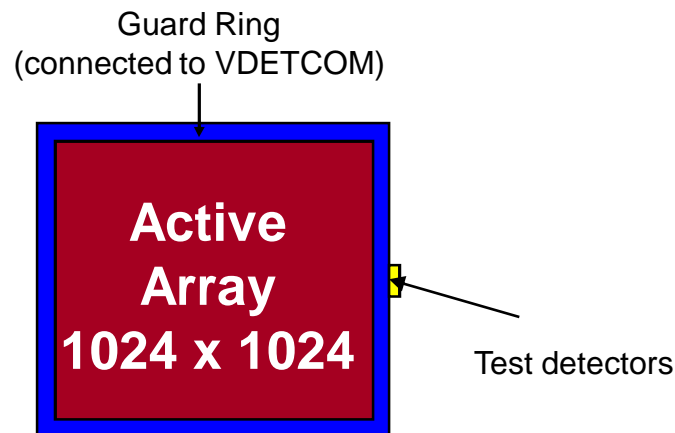
ROIC Overview

- **Name: ISC0501**
- **Format: 1024 x 1024 pixels (1 megapixel)**
- **Pixel Pitch: 30µm**
- **Detectors: GaAs / AlGaAs QWIPs**
- **Two-color**
 - MWIR (4-5µm) & LWIR (8-9µm)
 - One detector of each color per 30µm pixel
 - 2 colors are pixel co-located
 - Separate signal paths for each color for optimization of:
 - Detector bias
 - Integration time
 - Offsets
 - Gains
 - Simultaneous readout of pixel data from both colors
- **Frame Rate: 60Hz for full frame readout of both colors**
 - 5MHz input clock
 - 10MHz pixel rate output on 8 analog outputs per color
- **Operating temperature 60K to 77K**
 - Functional at 300K for testing purposes



Detector Interface: Overview

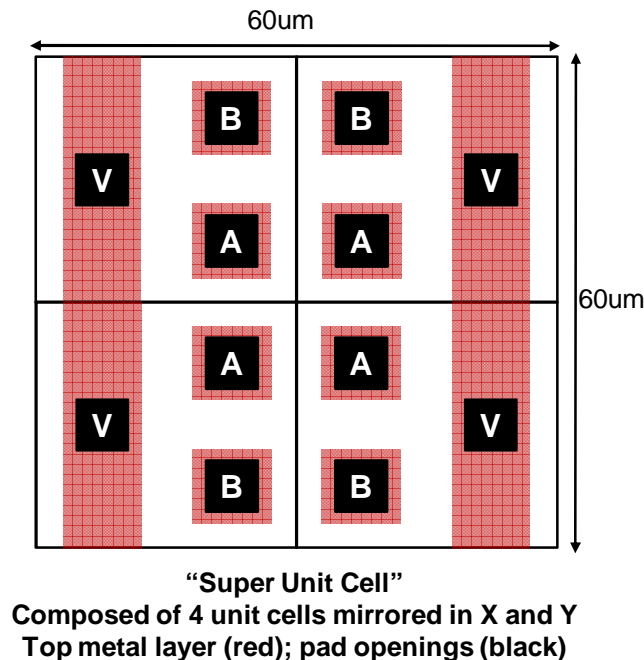
- **Array of 1030 x 1030 pixels**
 - Active array is the center 1024 x 1024 pixels
 - Guard ring of 3 pixels around active array
 - All pad openings in guard ring are tied to the detector common bias (VDETCOM bias) on the ROIC
- **4 Test detectors outside of the VDETCOM guard ring on the right side of the array**
 - All pad openings in test detector pixels are wired to 100μm x 100μm pads for probing





Detector Interface: Unit Cells

- **Three pad opening per unit cell (pixel)**
 - A: Connects one terminal of MWIR QWIP detector to ROIC signal path A
 - B: Connects one terminal of LWIR QWIP detector to ROIC signal path B
 - V: Connects shared terminal between the QWIPs to global detector common bias (VDETCOM)
- **Unit cells are mirrored in X and Y to make a super unit cell**
- **Super unit cells are stepped in both X and Y**





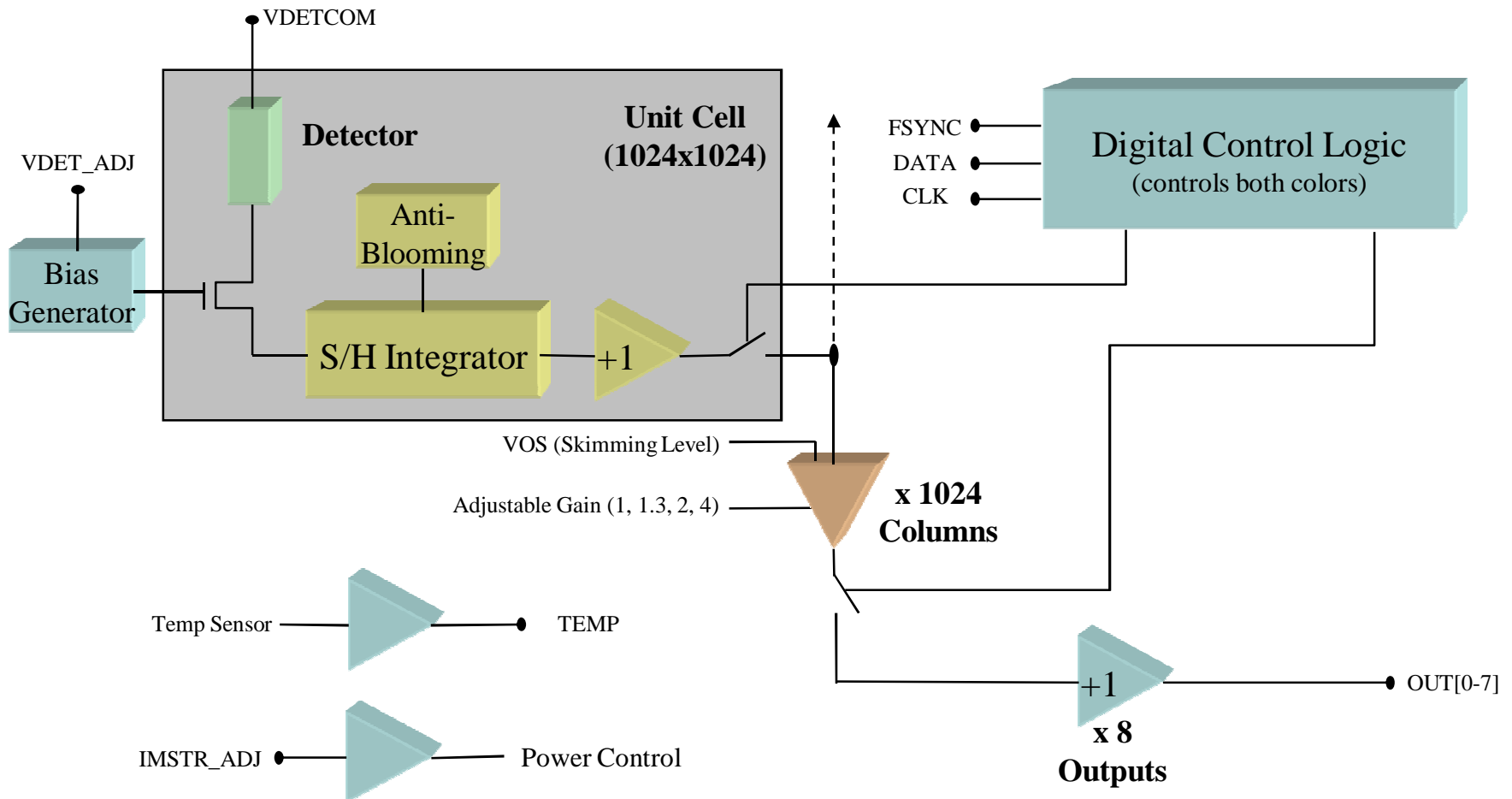
Analog Design: Overview

- **Analog signal path buffers and pre-processes the detector signal from the detector to the output of the ROIC**
 - Separate set of circuitry for each color from the detector interface in each unit cell through the output drivers
 - Controls available in the logic to independently adjust each color's signal path



Analog Design: Signal Path

- **Signal path shown for one color**
 - Circuitry for two identical signal paths exists on the ISC0501 ROIC





Analog Design: Unitcell

- **Detector bias voltage**
 - Adjustable independently per color
 - Adjustments can be made through the VDET_ADJA and VDET_ADJB pads
 - Adjustments can also be made through the serial control register if the VDET_ADJ* pads are left floating
- **Direct injection (DI) input circuit**
 - Sets detector bias
 - Allows detector current to flow into the ROIC
 - Low power
 - Small circuit size allows for high charge storage capability
- **Separate integration capacitors in each signal path to integrate and store detector signal**
 - MWIR (color A): ~4.2 million electrons charge capacity
 - LWIR (color B): ~16.7 million electrons charge capacity
- **Anti-blooming circuitry**
 - Prevents high detector current from de-biasing the detector
- **Circuitry in unitcell designed for snapshot integration in two modes**
 - Integrate-Then-Read (ITR)
 - Integrate-While-Read (IWR)
- **Data sent out of the unit cell through a column buffer**
 - Read out of unit cell during the line time in a pipelined fashion



Analog Design: Column Amplifier

- **Voltage mode column amplifier allows for analog signal processing in the ROIC signal path**
- **Adjustable gain per color**
 - 1.0x, 1.3x, 2.0x or 4.0x
 - Set using the serial control register
- **Adjustable offset (skimming) per color**
 - Skimming is used to remove detector dark current
 - When on, skimming level set using pads
 - MWIR skimming: VOSA pad
 - LWIR skimming: VOSB pad
 - Turned on / off using the serial control register
- **Adjustable reference level of column amplifier to optimize range and linearity of the analog signal path**
 - MWIR reference level: VREFA pad
 - LWIR reference level: VREFB pad



Analog Design: Output Drivers

- **Eight analog output drivers per color**
 - Pixel rate of up to 10MHz
 - Option to only turn on 4 output drivers per color
 - Set in serial control register
- **Data of each pixel is sent out simultaneously for color A and color B**
- **During line dead time outputs are set to a reference level**
 - VOUTREFA1 is the MWIR reference level during odd rows
 - VOUTREFA2 is the MWIR reference level during even rows
 - VOUTREFB1 is the LWIR reference level during odd rows
 - VOUTREFB2 is the LWIR reference level during even rows
- **Optional reference output for each color**
 - Allows common mode noise to be subtracted at the system level at the expense of increased ROIC noise and increased ROIC power
 - Input to the reference circuitry:
 - VOUTREFA1 is the MWIR reference circuit input during odd rows
 - VOUTREFA2 is the MWIR reference circuit input during even rows
 - VOUTREFB1 is the LWIR reference circuit input during odd rows
 - VOUTREFB2 is the LWIR reference circuit input during even rows
 - Turned on / off through serial control register



Analog Design: Adjustability

- **Analog signal path can be optimized and tested through the serial control register and external pads**
 - All adjustments previously described in analog signal path
 - Power adjustments
 - IMSTR_ADJA: Global adjust of power for MWIR from pad
 - IMSTR_ADJB: Global adjust of power for LWIR from pad
 - Can adjust power of each color independently through the serial control register
 - Power adjustments are not typically necessary
 - Can be used during initial testing of the ROIC
 - Advanced users can optimize power and performance of the analog signal path



Digital Design: Overview

- **Digital design is used to control the functions of the ROIC**
 - Provides an interface to the chip to control the operating modes
 - Controls the flow and multiplexing of each color's analog signal path



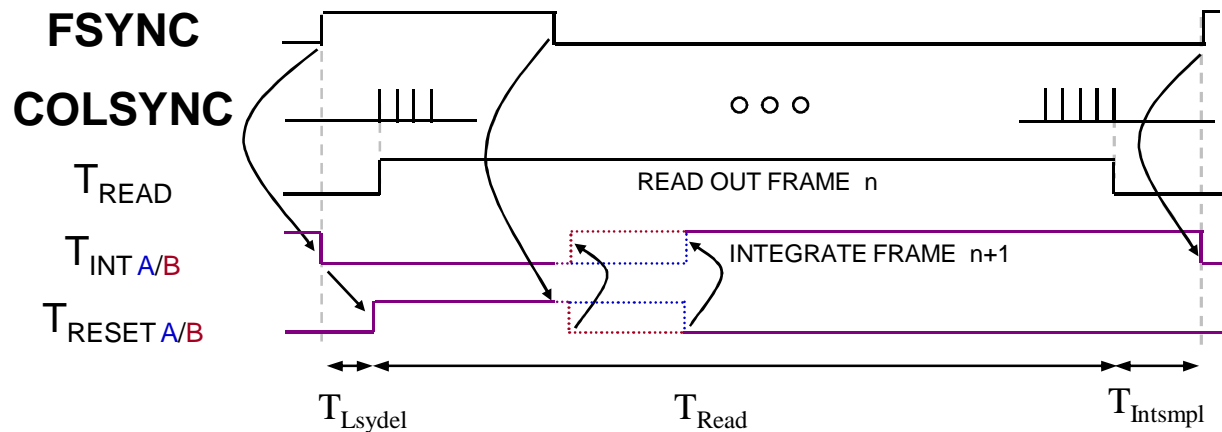
Digital Design: User Interface

- **Control word applied through a serial control register sets the operating mode of the ROIC**
 - “Start” bit begins reading in the control register word
 - 127-bit long word
 - One word per frame
 - If no word is sent during a frame, the setting of the previous frame remains unchanged
- **Command Register Controls The Following Functions:**
 - On-Chip Bias Control
 - Skimming Enable (per color)
 - Gain Control (per color)
 - Detector Bias Adjustment (per color)
 - Reference Output Enable
 - Anti-Bloom Enable
 - Variable Line Dead Time
 - Integration Times (per color)
 - Row Windowing Size / Row Windowing Location
 - Invert Mode
 - Integration Mode
 - Output Mode
 - Test Row
 - Programmable Test
 - Global Reset

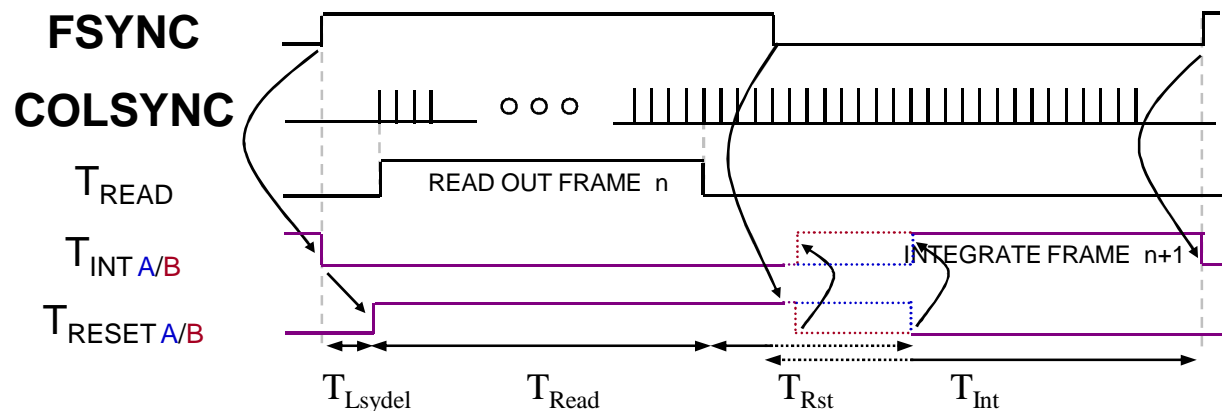


Digital Design: ITR & IWR Integration / Readout Modes

- **Integrate While Read:** Fastest frame rate but reduced performance



- **Integrate Then Read:** Slower frame rate with increased performance

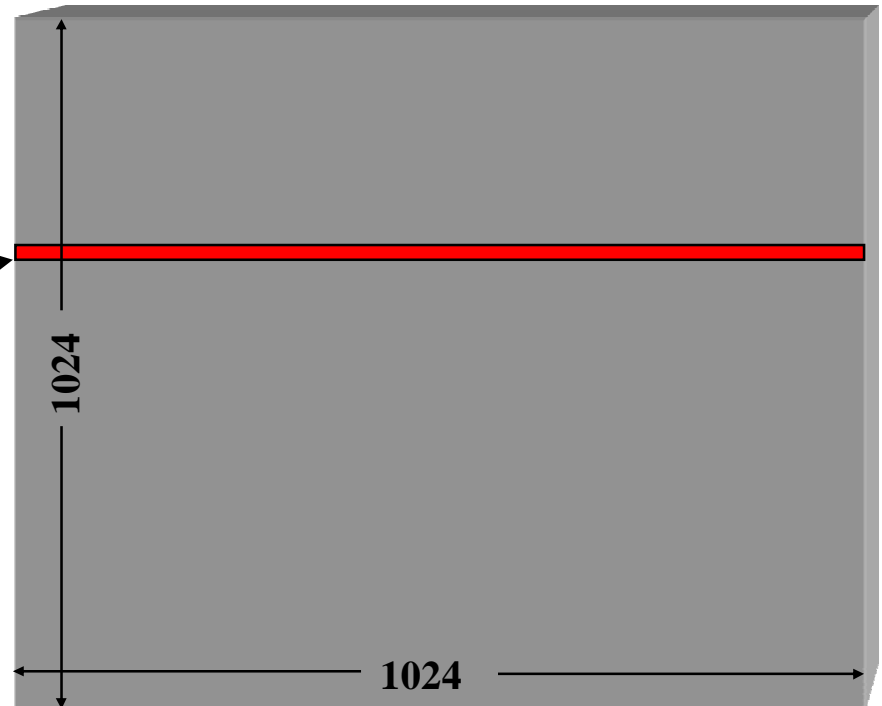


Differences in integration times between the two colors are set through bits in the serial command register in both ITR and IWR modes



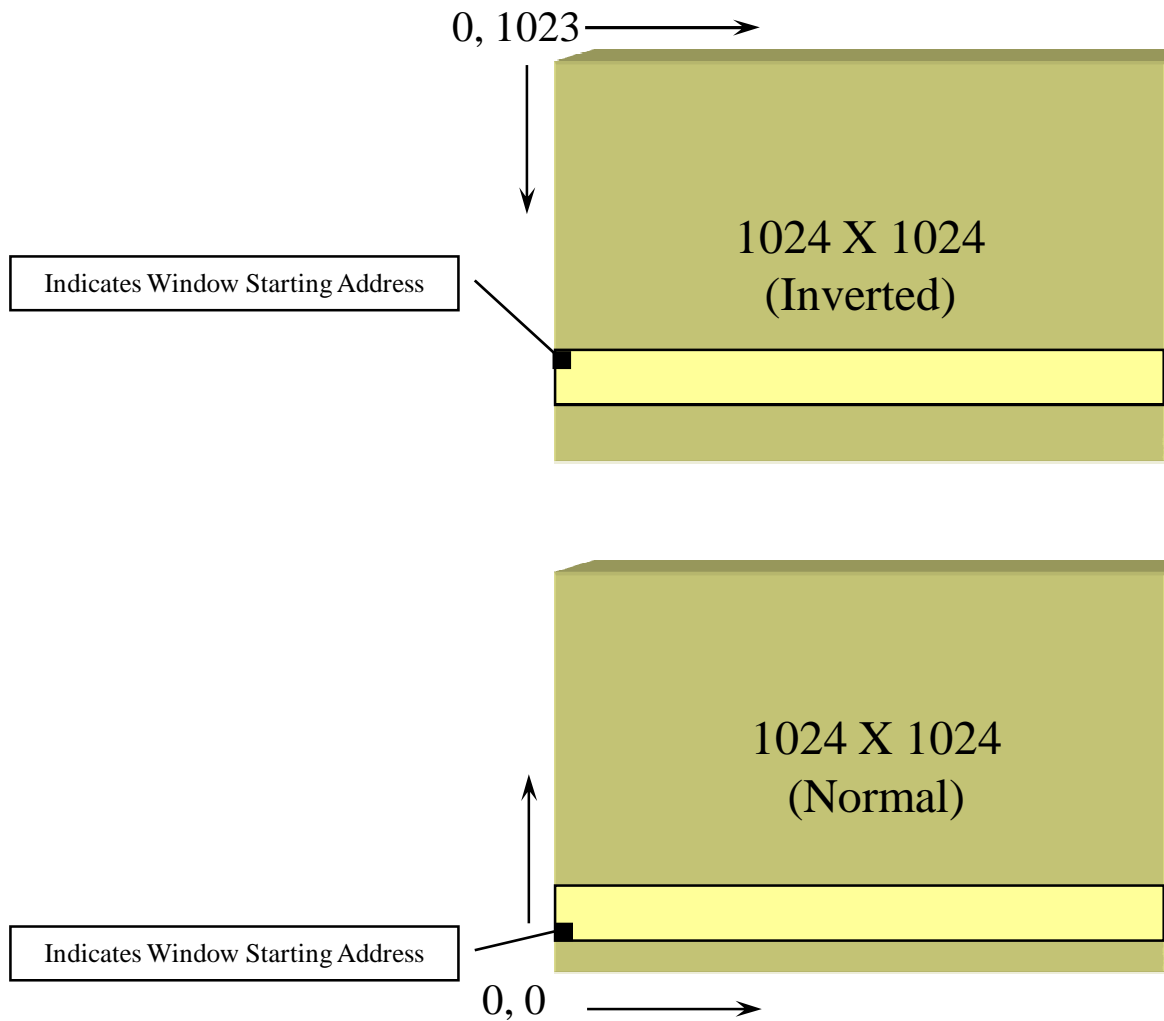
Digital Design: Windowing Operation

- **Windowing In Row Dimension Only**
- **Window Size and Location Resolution Of 1 Row**
- **Smallest Window**
 - 1024x1
 - Readout Rate = 3,366Hz
 - 170us Integration Time (IWR)





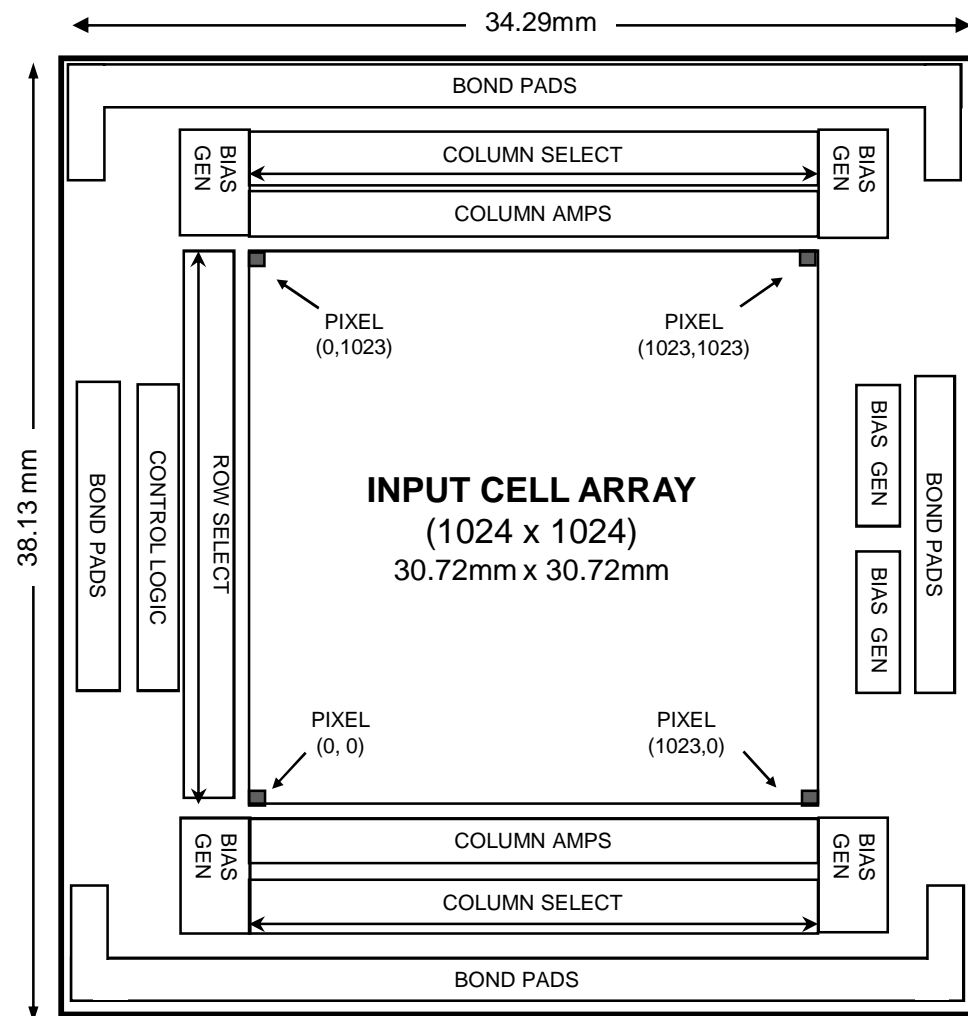
Digital Design: Readout Order





Physical Design: Overview

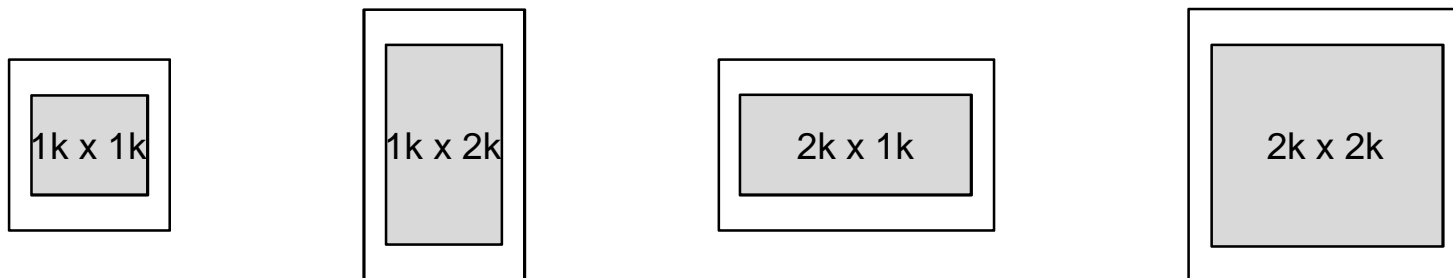
- **Standard CMOS mixed signal process**
 - 0.5 μ m transistors
- **Die size of 34.29mm x 38.13mm**
 - 16 die per 8-inch wafer
- **Block diagram of layout**
 - Not to scale





Physical Design: Modular Layout

- **Circuitry and layout designed to allow for expandability from 1k x 1k array to up to 2k x 2k**
 - As size increases in the X direction the number of output drivers of each color increases
 - An ROIC with 2048 rows must set a bit in the serial control register to allow correct row windowing and scanning
- **Decreased performance with larger array sizes**
 - Increase power
 - Decreased maximum input clock rate and maximum output data rate
 - Decreased frame rate
 - Reduced image performance
- **Arrays sizes other than 1k x 1k have yet to be fabricated or tested**



ROICs with different array sizes
Active array in gray. Pictures not to scale.



Performance: Test Results

- Characterization was completed on the ISC0501 ROIC at 77K
- Only Linearity in IWR did not meet specification

Function	Test Results	Compliance
Full Scale Swing	$\geq 2.0V$	YES
Linearity ITR	Less than Spec	YES
Linearity IWR	Slightly above Spec	NO
Multiple Outputs	4 or 8 per color	YES
Invert	Reverse row order	YES
Power	$\leq 600mW$ 8 output	YES
Power Adjust	Functional	YES
Windowing	Functional	YES
Integration Mode	ITR and IWR	YES
Integration Control	Adjustable per color	YES
Detector Bias	Functional	YES
Temperature Diode	0.7V \pm 0.05V @ 300K 1.07V \pm 0.05V @ 77K	YES
Reference Output	Functional	YES
Noise (MWIR/A)	Less than Spec	YES
Noise (LWIR/B)	Less than Spec	YES
Data Rate	$\geq 10MHz$	YES
Gain	1x, 1.3x, 2x, 4x	YES
Skimming	Functional	YES
Adjust line time	Functional	YES
Crosstalk color to color	Less than Spec	YES
Crosstalk	Less than Spec	YES



Performance: Image from FPA using the ISC0501 ROIC

- FPA developed by JPL using the ISC0501 ROIC hybridized with JPL's QWIP detectors



MWIR:
Ability to see hot CO₂ gas in
MWIR band, creating a longer
looking flame

LWIR:
Readout at the same time as
the MWIR image, but CO₂ gas
is not detected in LWIR band

Summary

- **Two-color one megapixel ROIC provides a user with large amounts of data not available with older generation ROICs**

- ISC0501 two-color 1k x 1k
- HDTV

1-color standard format ROIC
standard black and white



- **Extra information makes each object more distinct**
 - Faster and easier detection of objects
 - Applications in military, medical, geological, astronomy and commercial fields
- **All two-color circuitry is designed at the QWIP detector level and the ROIC level**
 - Reduced complexity at system level → reduced cost at system level
- **Large set of adjustments on ISC0501 ROIC**
 - Allows for an FPA to be produced to that can meet requirements and be optimized for many different applications